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United States Patent Application

of

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for

Method and System for

Establishing Trust in Downloaded Proxy Code

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RELATED APPLICATION

The present application is related to U.S. Provisional Patent Application No. 60/128,406, entitled "RMI Security," filed April 8, 1999, which is relied upon and is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to data processing systems and, more particularly, to using downloaded code to provide secure communication between a client and a remote service in a distributed system.

BACKGROUND OF THE INVENTION

Today's distributed systems can be made up of various components, including both hardware and software. Nodes in distributed systems typically communicate via a network such as the Internet. One means of communication between programs in a distributed system is downloading code from one program to another. For example, a client (e.g., a program running on a node in a distributed system) can access a service running on a remote node by downloading code from the remote service.

A "service" refers to a resource, data, or functionality that can be accessed by a user, program, device, or another service and that can be

computational, storage related, communication related, or related to providing access to another user. Examples of services include devices, such as printers, displays, and disks; software, such as applications or utilities; information, such as databases and files; and users of the system.

5 In a distributed system implemented using the Java™ programming language, services appear programmatically as objects, with interfaces that define the operations available from the service. In the Java™ programming language, a "class" provides a template for the creation of "objects" (which represent items or instances manipulated by the system) having characteristics of that class. Thus, a class defines the type of an object. Methods associated with a class are generally invoked on the objects of the same class or subclass. The Java™ programming language is described in The Java™ Language Specification by James Gosling, Bill Joy, and Guy Steele, Addison-Wesley, 1996, which is incorporated herein by reference.

15 In a distributed system that depends on downloaded code, there is the danger that the downloaded code may be untrustworthy. For example, the code could carry a virus or disguise its true source, causing the user of the downloaded code to disclose confidential information to an unknown party. Therefore, it is desirable to enable users in a distributed system to confirm that downloaded code is trustworthy.

SUMMARY OF THE INVENTION

5 A system consistent with the present invention enables a user in a distributed system to determine whether downloaded code is trustworthy before using the downloaded code to communicate with others in the distributed system. For example, if a client downloads code from a service, the client can verify that both the service and the downloaded code are trustworthy before using the code to communicate with the service. "Trustworthy" code is code that the client knows will enforce the client's security constraints (e.g., mutual authentication, confidentiality, and integrity) when communicating with the service.,

10 In accordance with one implementation of the present invention, code is downloaded from a server, and a set of constraints to implement secure communication with the server is determined. Secure code is then used to verify that the downloaded code will enforce the set of constraints when the downloaded code is used to communicate with the server.

15 In accordance with another implementation of the present invention, a first proxy containing code for communication purposes is downloaded, and a second proxy containing code for communication purposes is obtained from the first proxy. A trustworthiness verification routine is used to determine whether the second proxy is trustworthy, and when it has been determined that the second proxy is trustworthy, the second proxy is used to determine whether a server is

trustworthy. When it has been determined that the server is trustworthy, a trustworthiness verification routine is requested from the server by using the second proxy and this verification routine is then used to identify the trustworthiness of the first proxy. When it has been determined that the second proxy is trustworthy, that the server is trustworthy, and that the first proxy is trustworthy, the first proxy is used to invoke a method on the server.

BRIEF DESCRIPTION OF THE DRAWINGS

This invention is pointed out with particularity in the appended claims. The above and further advantages of this invention may be better understood by referring to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 depicts a distributed system suitable for practicing methods and systems consistent with the present invention;

Fig. 2 depicts the logical interaction between a client and a service once the client has downloaded a proxy;

Fig. 3 is a high-level flow chart of an exemplary method for establishing trust in a downloaded proxy in accordance with methods and systems consistent with the present invention; and

Figs. 4A and 4B are flow charts depicting the steps of the verifyProxyTrust method for establishing trust in a downloaded proxy.

DETAILED DESCRIPTION OF THE INVENTION

5 A distributed system suitable for practicing methods and systems
consistent with the present invention can be implemented using the Jini™
architecture. A Jini™ system is built around one or more lookup services that list
the services available in the distributed system. When a service joins the
network, it uses a process called discovery to locate the lookup service or
services for the network. The service registers by passing a proxy object to each
lookup service. The proxy object is a Java™ object implementing the interfaces
of the corresponding service. When a client (e.g., a program) wishes to use a
service, the client interacts with the lookup service and downloads the proxy to
facilitate use of the service. The Jini™ architecture is described in more detail in
Arnold, The Jini™ Specification, Addison-Wesley (1999).

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15 A system consistent with the present invention enables a program in a
distributed system to determine whether downloaded code is trustworthy before
using the downloaded code to communicate with other programs or services in
the distributed system. For example, if a client downloads code from a service,
the client can verify that both the service and the downloaded code are
trustworthy before using the code to communicate with the service.

"Trustworthy" code is code the client knows will enforce the client's security
constraints in communicating with the service.

5 These constraints can include, for example, integrity, anonymity, mutual authentication, delegation, and confidentiality. The "integrity" constraint ensures that messages will not be tampered with in transit, the "anonymity" constraint permits the identity of the client to stay unknown to the service, and "mutual authentication" refers to the client and service verifying their identities to one another. The "delegation" constraint allows the service to make calls to other computers using the client's identity, and the "confidentiality" constraint ensures that messages are private, e.g., by using encryption.

10 The constraints attached to a proxy are included in the serialized version of the proxy. As part of RMI system 122, an object, such as a proxy, is converted into a serialized version of itself before being passed. The serialized object contains enough information to enable the recipient to identify and verify the Java™ class from which the contents of the object were saved and to restore the contents to a new instance. Object serialization is explained in the Java™
15 Object Serialization Specification, available at <http://web2.java.sun.com/products/jdk/1.3/docs/guide/serialization/spec/serialTOC.doc.html>, which is incorporated herein by reference. When a client trusts the downloaded code to enforce the client's security constraints and trusts the service, the client can trust communicating through the proxy to the service and can trust the service to do what the client asks, and not something harmful.

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for a proxy to the database service. In response, lookup service 138 returns proxy object 140 corresponding to database service 136 to the client. Lookup services are explained in greater detail in U.S. Patent Application No.09/044,931, entitled "Dynamic Lookup Service in a Distributed System," which is incorporated herein by reference.

Figure 2 depicts the logical interaction between client program 142 and service 136 once the client has downloaded proxy 140. Proxy 140 implements one or more interfaces 202 corresponding to the methods 204 offered by service 136. Client 142 invokes methods on proxy 140. Proxy 140 processes method invocations, communicates with service 136 to execute the requests of client 142, and returns results. The protocol between proxy 140 and service 136 is not set by the Jini™ system; instead, it is determined by the service and its proxy. This enables a client to communicate with a service it may have never seen before without knowing or caring how the service works.

In this way, the Jini™ architecture relies on downloaded code to provide services in a dynamic and flexible way. Once a client downloads a proxy object, the client invokes methods on the proxy to communicate with the remote service. However, the proxy may be implemented using code that the client does not trust. Before sharing any critical data with the service, the client needs to establish trust in the proxy, the service, or both.

Figure 3 is a high-level flow chart of an exemplary method for establishing trust in a downloaded proxy in accordance with methods and systems consistent with the present invention. The exemplary method enables a client to use code that can be verified locally to communicate with a remote service. Using the locally-verified code, the client verifies the remote service and then asks the service whether the service trusts the downloaded proxy. If the client has verified the service and the service trusts the proxy, then the client has established transitive trust in the proxy.

With reference to figure 3, the exemplary method begins when the client downloads the proxy, P1, from a lookup service (step 302). The client then asks P1 for a second proxy to the service, P2, by invoking a method on P1 corresponding to a method on the service (step 304). The client examines the code in P2 to verify that P2 uses only trusted code (step 306). If the client verifies P2 (step 307), then the client uses P2 to authenticate the service by invoking a method on P2 (step 308). If the service is authenticated (step 309), the client then uses P2 to ask the service if the service trusts P1's code, by invoking a method on P2 to obtain a proxy verifier from the service, and then passing P1 to the proxy verifier (step 310). If the service trusts P1 (step 311), then the client can trust P1 (step 312). In this manner, the client uses local, trusted code to establish trust in a downloaded proxy.

The VerifyProxyTrust method

The exemplary method described above will now be explained using the Java™ RMI Security Subsystem, part of RMI system 122. The Security Subsystem defines classes and interfaces that ensure secure communication between remote objects. One class provided by the RMI Security Subsystem is the Security class, which includes the verifyProxyTrust method. The verifyProxyTrust method establishes trust in downloaded code and is defined as follows:

```
public static void verifyProxyTrust (  
    Object proxy,  
    SecurityConstraints constraints)  
    throws RemoteException;
```

The verifyProxyTrust method in RMI system 122 is called by client 142 once the client downloads proxy 140, before the client makes any other use of the proxy. As described below, the method will establish trust in the proxy by confirming that the proxy will correctly implement the RemoteSecurity interface, part of the Security class.

When a remote service instantiates its proxy, the service can include the RemoteSecurity interface, which provides methods enabling a client to attach security constraints to the proxy or to query the service to determine the service's security constraints. The RemoteSecurity interface is defined as follows:

```
public interface RemoteSecurity {  
    RemoteSecurity setClientConstraints (  
        SecurityConstraints constraints);  
}
```

```
SecurityConstraints getClientConstraints();
SecurityConstraints getServerConstraints (String name,
                                         Class[] parameterTypes);
    throws NoSuchMethodException, RemoteException;
boolean equalsIgnoreConstraints(Object obj);
}
```

The setClientConstraints method allows a client to make a copy of the proxy with a new set of constraints selected by the client. The getClientConstraints method returns the current client constraints attached to the proxy. The getServerConstraints method returns the server's constraints for a particular remote method implemented by the proxy.

As explained above, the constraints can include, for example, integrity, anonymity, mutual authentication, delegation, and confidentiality. When the verifyProxyTrust method determines that the proxy will enforce the client's constraints by correctly implementing the RemoteSecurity interface, the proxy is "trusted."

Figures 4A and 4B are flow charts showing the steps of the verifyProxyTrust method. When a client calls verifyProxyTrust, the call has as its parameters the proxy and the client's security constraints.

As shown in steps 402 to 410 of Figure 4A, the verifyProxyTrust method first determines whether the downloaded proxy is a secure RMI stub. A stub is one example of a proxy, created by the RMI System, that uses the RMI protocol to communicate with a service. A secure RMI stub is an instance of a class generated by the java.lang.reflect.Proxy class provided by the Java™

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invocation handler of the proxy, and the verifyProxyTrust method then calls the local instanceof operator to determine whether the proxy's invocation handler is an instance of a local trusted class,

SecureInvocationHandler. The local trusted class SecureInvocationHandler is specified in the Security class in RMI 122. The corresponding local calls made by verifyProxyTrust are:

```
Proxy.isProxyClass(proxy.getClass())
handler = Proxy.getInvocationHandler(proxy)
handler instanceof SecureInvocationHandler
```

As explained above, these methods are provided by the java.lang.reflect.Proxy class of the Java™ programming language.

If the proxy is an instance of a trusted class and the invocation handler is secure, then each socket factory instance contained in the invocation handler is checked (step 406). A socket is an end-point to a communication path between two processes in a network. A socket factory is an object that implements a method to create a new socket. Socket factories are described in more detail at <http://java.sun.com/products/jdk/1.3/docs/api/java/net/SocketImplFactory.html>. The class of each socket factory instance in the proxy is compared to a local list of trusted socket factory classes.

To obtain the list of trusted socket factory classes, the verifyProxyTrust method uses a local configuration database to obtain TrustVerifier.

TrustVerifiers are provided as part of the Java™ RMI Security Subsystem in RMI system 122, and are defined as follows:

```
public interface TrustVerifier {  
    boolean trustedConstraintClass(Class c);  
    boolean trustedPrincipalClass(Class c);  
    boolean trustedClientSocketFactoryClass(Class c);  
    boolean trustedProxy(Object proxy,  
                          SecurityConstraints constraints)  
        throws RemoteException;  
}
```

The local configuration database contains a list of TrustVerifier instances that implement methods for testing the security of a given proxy or class. The trustedClientSocketFactoryClass method will return true if the given class is a trusted socket factory class defined in RMI 122. For each socket factory instance in the proxy, the verifyProxyTrust method calls the trustedClientSocketFactoryClass method of each TrustVerifier instance, passing the socket factory class as a parameter. If at least one trustedClientSocketFactoryClass method returns true for each socket factory, the proxy is a secure RMI stub (step 408). If the proxy is not an instance of a trusted Proxy class, or if the invocation handler is not secure, or if the socket factories are not trusted, then the proxy is not a secure RMI stub (step 410).

Before continuing with the description of figure 4A, it is important to understand the difference between a unicast and an activatable stub. An RMI stub can be either unicast or activatable, depending on how it was exported by the service it represents. A unicast stub works until its service goes down. By

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downloaded, e.g. a uniform resource locator (URL). The signer information identifies the creator or creators of the code, i.e., the activator verifier.

Because the verifier could have been downloaded, the verifyProxyTrust method checks that the activator verifier can be trusted using the codebase and signer information (step 416). If the service returned codebase information, the verifyProxyTrust method calls a local RMIClassLoader.getClassAnnotation method, which returns the location where the activator verifier code was obtained. The verifyProxyTrust method compares that location to the codebase information from the service. If they are different, the activator verifier is not used because its code is not trusted. If one or more signers is specified by the service, the verifyProxyTrust method obtains the signers of the verifier by calling the local Class.getSigners method and compares them to the signers specified by the service. If they are different, the activator verifier is not used because its code is not trusted.

In this way, the verifyProxyTrust method uses local methods to confirm the activator verifier code, which may have been downloaded and therefore could be corrupted. If the service did not specify either codebase or signer information, the verifyProxyTrust method confirms that the activator verifier was not downloaded, i.e., that the activator verifier is local, and therefore trusted. To do this, the verifyProxyTrust method compares the classloader of the verifier's class to the context classloader of the current thread or an ancestor of the

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